# A strategy to evaluate the surface energy of high packing efficiency fine powders via inverse gas chromatography

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## ARTICLE INFO

## ABSTRACT

The determination of the surface energy of free-flowing fine powders through IGC analysis can be technically challenging. These powders can have high packing efficiencies that can often lead to excessive gas pressure build up as the mobile phase passes through the stationary phase. As such, free-flowing fine powders may not necessarily be readily suitable to form the stationary phase of an IGC system. To alleviate this challenge, large carrier particles, in the form of silanized glass powders, can be blended with the free-flowing fine powder, in a manner that aids in disrupting the packing efficiency. However, the major concern here is that the introduced foreign material can potentially interfere with the probing of the sample of interest.

This research found that blending 250 μm silanized glass beads with a free-flowing fine powder can effectively reduce the pressure build up to prevent the system from over-pressuring. Additionally, it was observed that there is a critical mass for the sample of interest. Below this critical mass, the introduction of the carrier particles can interfere with the determination of the surface energy of the sample, where the surface energy was underestimated. However, above this critical mass, the introduction of the carrier particle does not significantly influence the surface energy determination of the sample of interest. It is therefore concluded that blending free-flowing fine powders with large carrier particles is a potential approach to resolve the challenge of over-pressured systems, provided the mass of the powder of interest is above the critical mass for that powder.

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## 1. Introduction

Determination of the surface energy of a fine powder is of particular interest to many material applications, as this energy is directly related to their cohesive inter-particulate interactions. Thus the surface energy can influence the bulk performances of powders, such as powder flow out of a hopper and into a tablet die during pharmaceutical tablet manufacturing [1–5]. One of the most common methods to measure the surface energy of bulk powders is through inverse gas chromatography (IGC) [6–12]. Similar to conventional gas chromatography (GC), IGC consists of a stationary phase and a mobile phase. However, unlike GC methods, the stationary phase of IGC is the sample of interest, in this case a powder; while the mobile phase comprises a series of known vapours [13,14]. However, not all powders are suitable for IGC analysis. For example, the porosity or the packing efficiency of a powder bed can be a critical factor in determining whether the powder is suitable to form the stationary phase of an IGC.

Generally, powders that either consist of relatively large particle sizes or that are highly cohesive tend to have packing efficiencies that are likely to produce appropriately porous powder beds [5]. Accordingly, the pressure drop across the stationary phase is likely to be within measurable limits and thus over-pressuring of the system is unlikely. Conversely, powders with high packing efficiencies, for instance free-flowing fine powders, are likely to produce powder beds with low porosity [5]. The mobile phase can then experience a much higher resistance while passing through the stationary phase; thus the pressure drop across the stationary phase can exceed the upper measurable limit: the system over-pressures. This can be problematic to surface energy determination as accurate retention volumes for the vapour probes cannot be determined, where the compression of the mobile phase within the column cannot be corrected for [15]. Clearly, a robust methodology to determine the surface energy of high packing efficiency powders which otherwise produce over-pressuring is required.

Anecdotal evidence suggests that blending free-flowing fine powders with large carrier particles may aid in increasing the porosity of the resultant powder bed; thus, in theory, reduce the likelihood of the system over-pressuring. However, the concern here is that a foreign surface is introduced. This may, therefore, influence the surface energy determination as the vapour probes could potentially probe the surface of the carrier particles instead of the sample of interest, and thus provide misleading surface energy data. However, this could be resolved for carrier particles with low surface energy surfaces, for instance large silanized glass powders, as their surface energy is expected to be low. Consequently, as the probes are assumed to interact primarily with the highest energy sites [16–19], it is expected that the surface of such

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carrier particles can be considered inert. Additionally, because the carrier particles are much larger than the powders of interest, the total surface area presented by the carrier particles would be significantly smaller than the surface area of the powder of interest. Thus, in theory, the large carrier particles should not interfere to any meaningful extent with the surface energy analysis.

The purpose of this paper is to evaluate the suitability of blending large silanized glass particles with free-flowing fine powders to reduce the pressure drop across the stationary phase, thereby decreasing the likelihood of over-pressuring the system. Additionally, this paper aims to determine whether the introduction of carrier particles influences the measurement of the surface energy (including its components) of a fine powder.

## 2. Materials and methods

### 2.1. Materials

The model pharmaceutical active used for surface energy measurements was micron-sized glass beads (MGB), $d_{50} = 10$ μm, which was procured from Cospheric LLC (CA, USA). Magnesium stearate NF (MgSt) was obtained from Mallinckrodt Baker Inc. (NJ, USA). The carrier particles used were 250 μm pre-silanized glass beads, which were obtained from Sigma-Aldrich Co. LLC. (MO, USA). All silanized glass wool and pre-silanized glass columns were purchased from Surface Measurement Systems Ltd. (London, UK). GC grade decane, nonane, octane, heptane, hexane, dichloromethane, and toluene were obtained from Sigma-Aldrich Co. LLC. (MO, USA). All materials were used as received.

### 2.2. Dry coating

Dry coating of MGB with MgSt was achieved in an AMS-Mini mechanofusion system (Hosokawa Micron Corp., Osaka, Japan). Prior to dry coating, approximately 20 g of MGB with 0.1% w/w MgSt was blended in a tumble mixer (Turbula® T2F, Glen Mills Inc., NJ, USA) at 101 rpm (revolutions per minute) for 10 min. The blended samples were then dry coated at 500 rpm for 2 min and then 3000 rpm for another 10 min with a Nobilta angled blade process head. Water (22 ± 2 °C) was circulated through the built-in water jacket to prevent the temperature within the processing chamber from exceeding 25 °C. The dry coated samples are noted as M-MGB-0.1.

### 2.3. Blending fine powders with carrier particles

Blends of MGB with carrier glass beads (CGB) and M-MGB-0.1 with CGB was achieved by gentle agitation using a smooth-surface mortar and pestle for approximately 2 min with MGB:CGB and M-MGB-0.1:CGB proportions as described in Table 1.

### 2.4. Surface energy measurements

The surface energy of MGB and M-MGB-0.1 was determined with the use of an inverse gas chromatography instrument (iGC 2000, Surface Measurement Systems Ltd., London, UK) at infinite dilution.

The powder samples and blended samples (see Table 1) were packed into pre-silanized glass columns (300 × 4 mm ID). Both ends of the column were loosely stoppered with silanized glass wool to prevent sample movement. Packed columns were then gently tapped manually until no visible signs of voids, cracks, or channels.

Prior to surface energy measurements, the samples were first pre-conditioned with a stream of helium at a flow rate of 10 sccm (standard cubic centimetre per minute) for a period of 120 min at 303.15 K and 0% RH (relative humidity). To measure the surface energy, helium at 10 sccm was used to carry a series of n-alkane probes (GC grade decane, nonane, octane, heptane, and hexane) and specific

**Table 1**
Mass and blend proportion of MGB and CGB.

| Sample ID | Mass of MGB (g) | %CGB (w/w) | Estimated relative surface area (MGB:CGB)[a] |
|---|---|---|---|
| MGB_0.2-0 | 0.2 | 0 | |
| MGB_0.6-0 | 0.6 | 0 | |
| MGB_0.7-0 | 0.7 | 0 | |
| MGB_1.2-0 | 1.2 | 0 | |
| MGB_1.5-0 | 1.5 | 0 | |
| MGB_2.3-0 | 2.3 | 0 | |
| M-MGB-0.1_1.2-0 | 1.2 | 0 | |
| MGB_0.2-95 | 0.2 | 95 | 822 |
| MGB_1.5-50 | 1.5 | 50 | 15,625 |
| MGB_0.7-50 | 0.7 | 50 | 15,625 |
| MGB_0.7-70 | 0.7 | 70 | 6,696 |
| MGB_0.7-80 | 0.7 | 80 | 3,906 |
| M-MGB-0.1_1.2-70 | 1.2 | 70 | 6,696 |

[a] Calculation based on monodisperse spherical particles with a diameter of 250 μm for CGB and 10 μm for both MGB and M-MGB-0.1.

probes (dichloromethane and toluene) through the stationary phase to determine the dispersive surface energy, $\gamma_S^D$, and the specific free energy, $\Delta G^{SP}$, respectively. The concentration used for all probes was at 0.03 $p/p_0$ (where $p$ is the partial pressure and $p_0$ is the saturation vapour pressure) and the system was kept at 303.15 K and 0% RH. Dead volumes were based on the elution time of methane gas at 0.03 $p/p_0$; detection of the probes was achieved with a flame ionization detector (FID). Results were analysed via SMS-iGC analysis software v1.3 (Surface Measurement Systems Ltd., London, UK). Replicates of 3 were conducted for all samples.

$\gamma_S^D$ of the sample and $\Delta G^{SP}$ of both dichloromethane and toluene was calculated with the Schultz method [20]. However, through this method, $\Delta G^{SP}$ is obtained in units of energy per mole (kJ/mol) while $\gamma_S^D$ is in units of energy per area (mJ/m$^2$). The harmonization of these units was achieved through the use of Avogadro's number and the cross-sectional area of the vapour probe (refer to Table 2) [7,15,21,22]. $\Delta G^{SP}$ is related to the polar surface energy through the concept presented by Good-van Oss [23], Eq. (1):

$$\Delta G^{SP} = 2aN_A \left( \sqrt{\gamma_L^+ \gamma_S^-} + \sqrt{\gamma_L^- \gamma_S^+} \right) \tag{1}$$

where $a$ is the cross-sectional area of the probe, $N_A$ is Avogadro's number, $\gamma_L^+$ is the electron-acceptor parameter of the acidic probe, $\gamma_S^-$ is the electron-donor parameter of the sample surface (basic site), $\gamma_L^-$ is the electron-donor parameter of the basic probe, and $\gamma_S^+$ is the electron-acceptor parameter of the sample surface (acidic site).

As described in the work presented by van Oss et al. (1998) [24], the polar surface energy, $\gamma_S^P$, was calculated with Eq. (2):

$$\gamma_S^P = 2\sqrt{\gamma_S^+ \gamma_S^-} \tag{2}$$

The total surface energy, $\gamma_S^T$, of the sample is the additive components of $\gamma_S^D$ and $\gamma_S^P$ [24].

**Table 2**
The electron-acceptor parameter, $\gamma_L^+$; electron-donor parameter, $\gamma_L^-$; and cross-sectional area, $a$, of dichloromethane and toluene (Surface Measurement Systems Ltd., London, UK).

| Probe | $\gamma_L^+$ (mJ/m$^2$) | $\gamma_L^-$ (mJ/m$^2$) | $a$ ($\times 10^{-19}$ m$^2$) |
|---|---|---|---|
| Dichloromethane | 5.20 | 0 | 2.45 |
| Toluene | 0 | 2.30 | 4.60 |